LEAD TELLURIDE-BASED PHOTODETECTORS – A PROMISING ALTERNATIVE TO DOPED Si AND Ge

Dmitriy Khokhlov*, Dmitriy Dolzhenko, Ivan Ivanchik,
Konstantin Kristovskiy
Physics Department, Moscow State University, Moscow 119992, Russia
** E-mail: khokhlov@mig.phys.msu.su*

Dan Watson, Judy Pipher
Department of Physics and Astronomy, University of Rochester,
Rochester 14627-0171, NY, USA

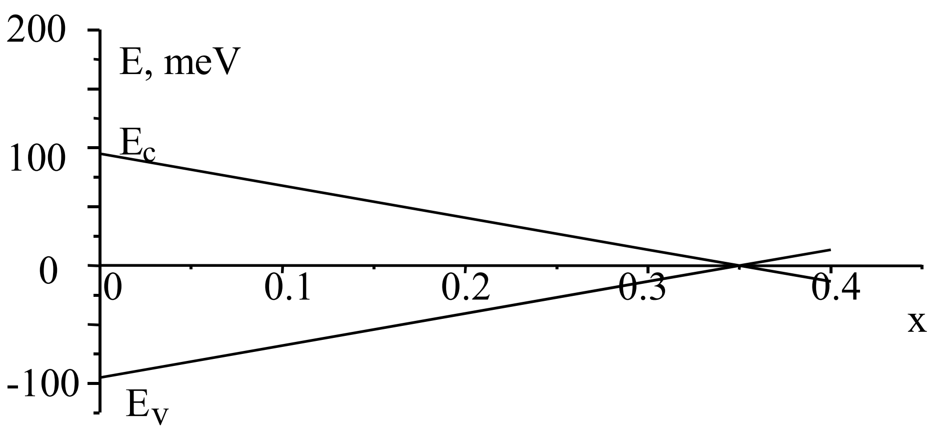
Juergen Wolf
German Aerospace Center (DLR), Institute for Space Sensor Technology
and Planetary Exploration, Rutherford Str. 2, 12489 Berlin, Germany

Undoped lead telluride-based alloys.

PbTe: narrow-gap semiconductor:

1. Cubic face-centered lattice of the NaCl type
2. Direct gap E_g = 190 meV at T = 0 K at the L-point of the Brillouin zone
3. High dielectric constant $\varepsilon \sim 10^3$.
4. Small effective masses $m \sim 10^{-2}\ m_e$.

$Pb_{1-x}Sn_xTe$ solid solutions:



Origin of free carriers:

deviation from stoichiometry ~ 10^{-3}.

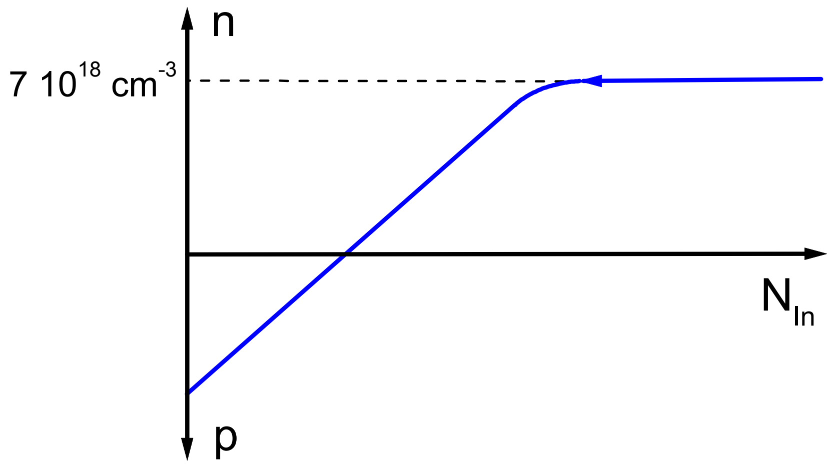
As-grown alloys: $n,p \sim 10^{18}$-10^{19} cm^{-3}

Long-term annealing: $n,p > 10^{16}$ cm^{-3}

Effects appearing upon doping.

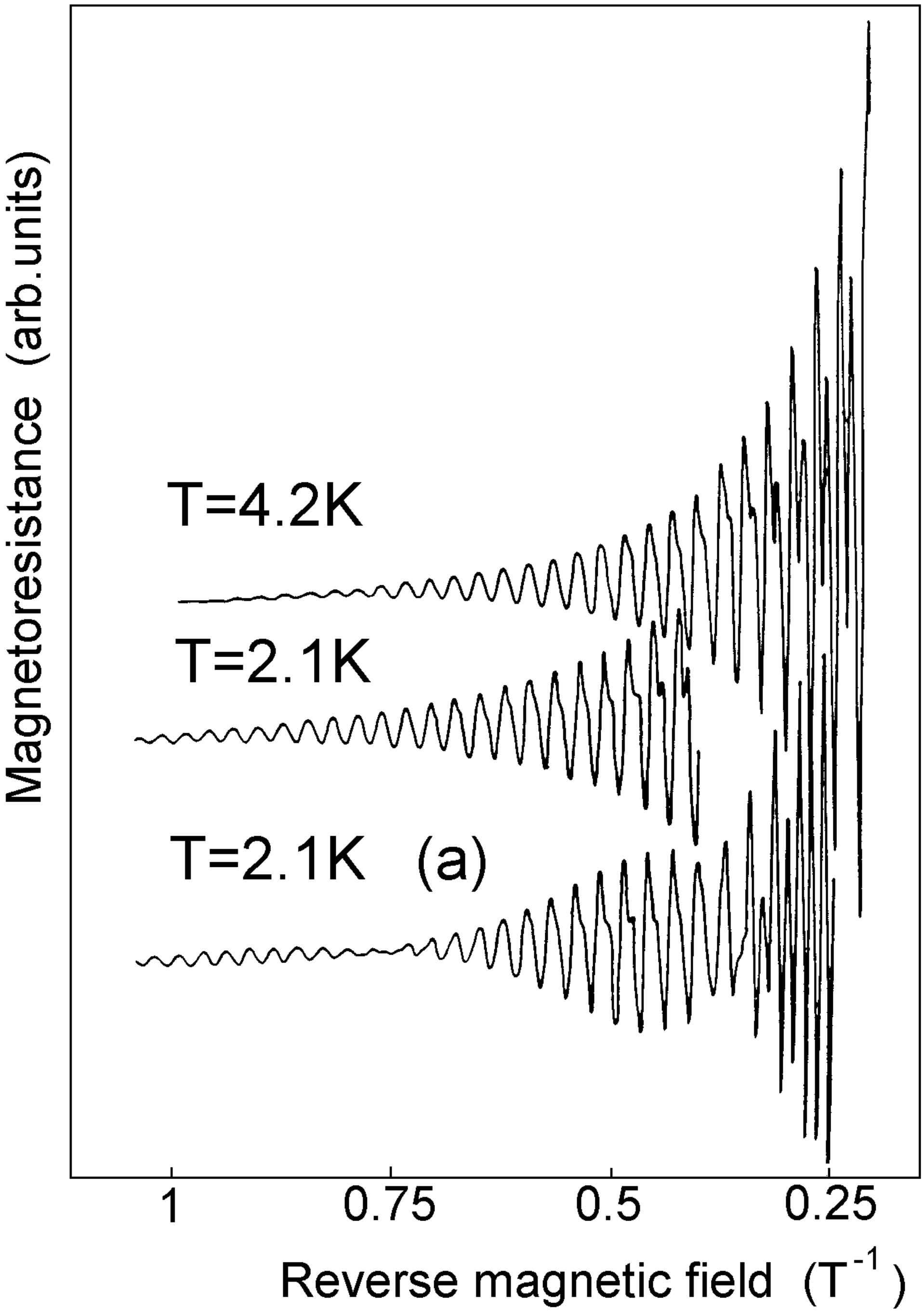
Fermi level pinning effect.

PbTe(In), $N_{In} > N_i$



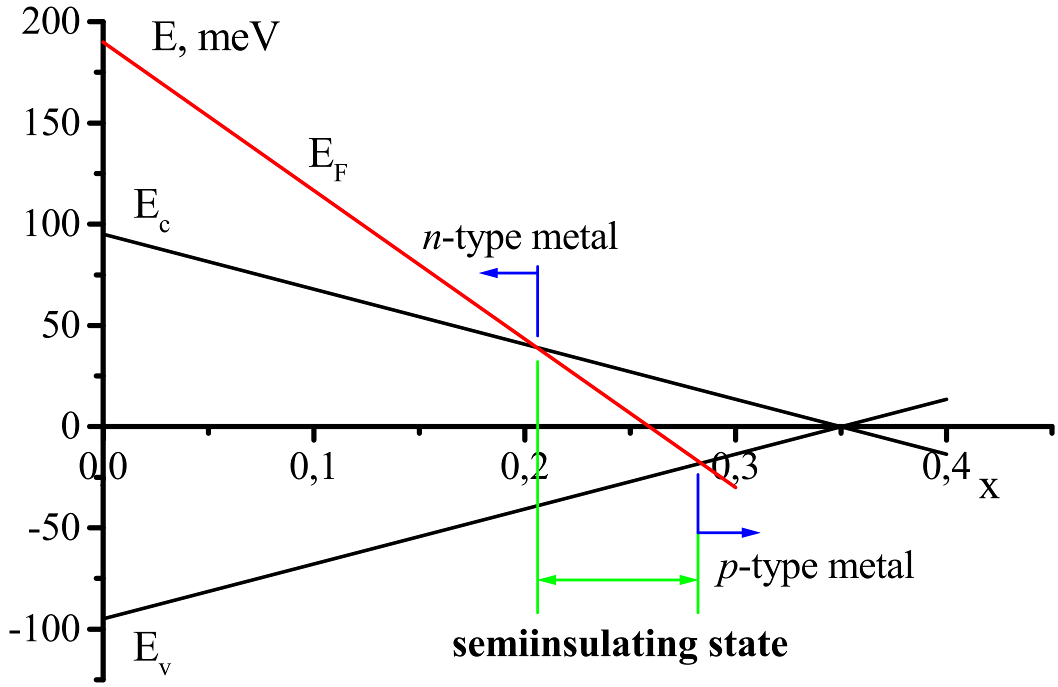
Consequences:

1. **Absolute reproducability** of the sample parameters independently of the growth technique. Therefore **low production costs**.
2. Extremely **high spatial homogeneity**.
3. **High radiation hardness** (stable to hard radiation fluxes up to 10^{17} cm^{-2})



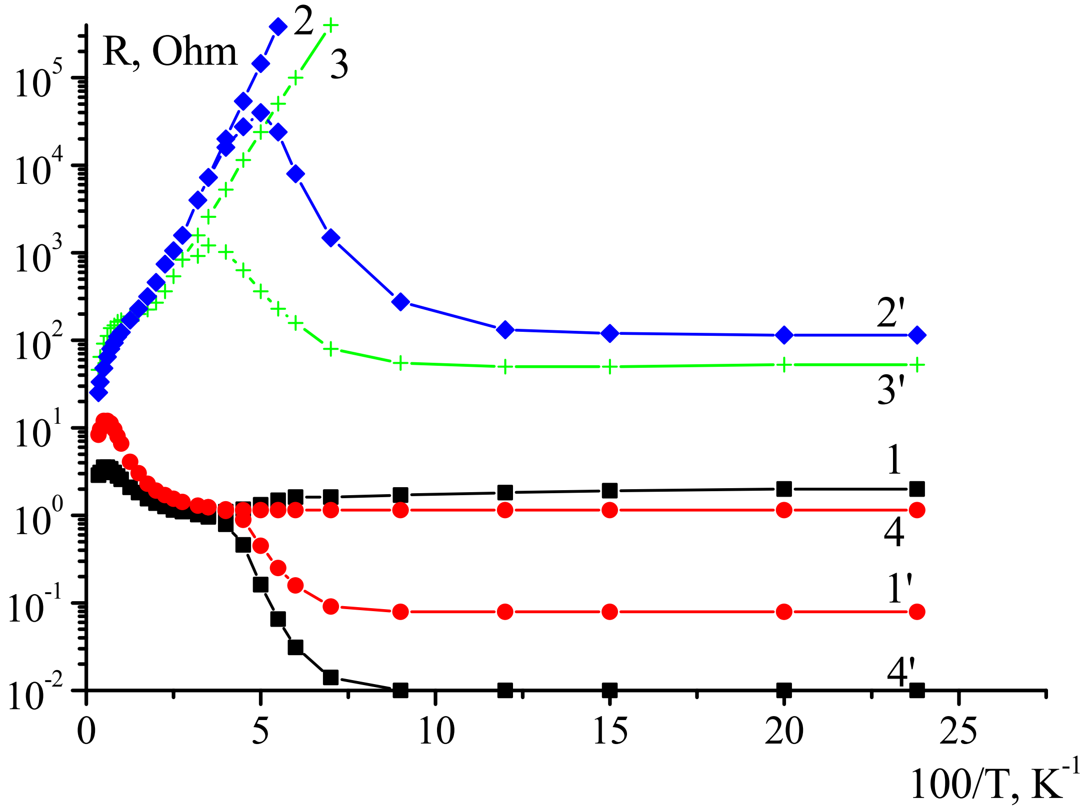
In PbTe(In) with the pinned Fermi level up to 50 periods of the Shubnikov-de Haas oscillations are resolved indicating very high degree of the sample homogeneity

Fermi level pinning in the $Pb_{1-x}Sn_xTe(In)$ alloys.



A very unusual situation is realized, when **a heavily doped narrow-gap semiconductor with high number of growth defects acts as an almost ideal semiconductor** with practically zero background free carrier concentration and very high electrical homogeneity.

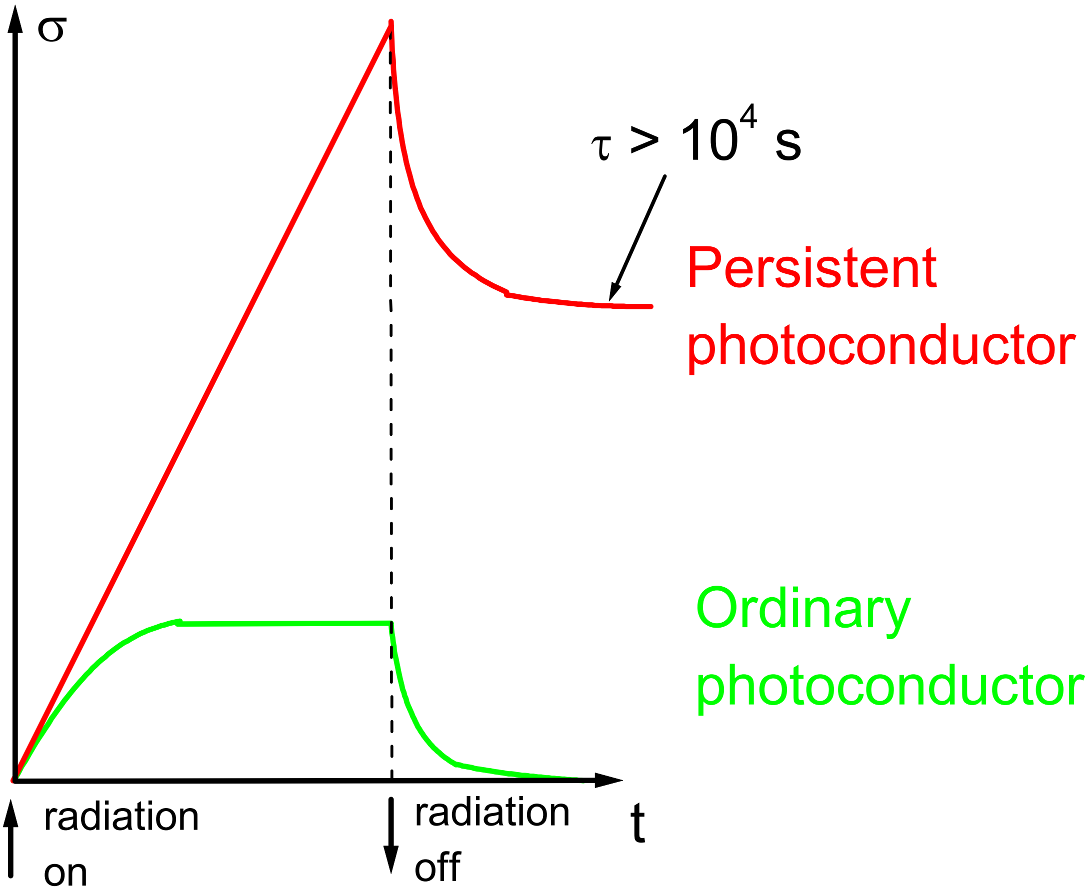
<u>Persistent photoconductivity</u>



Temperature dependence of the sample resistance R measured in darkness (1-4) and under infrared illumination (1'-4') in alloys with x = 0.22 (1, 1'), 0.26 (2, 2'), 0.27 (3, 3') and 0.29 (4, 4')

High photoresponse – consequence of the persistent photoconductivity.

Photoconductivity kinetics



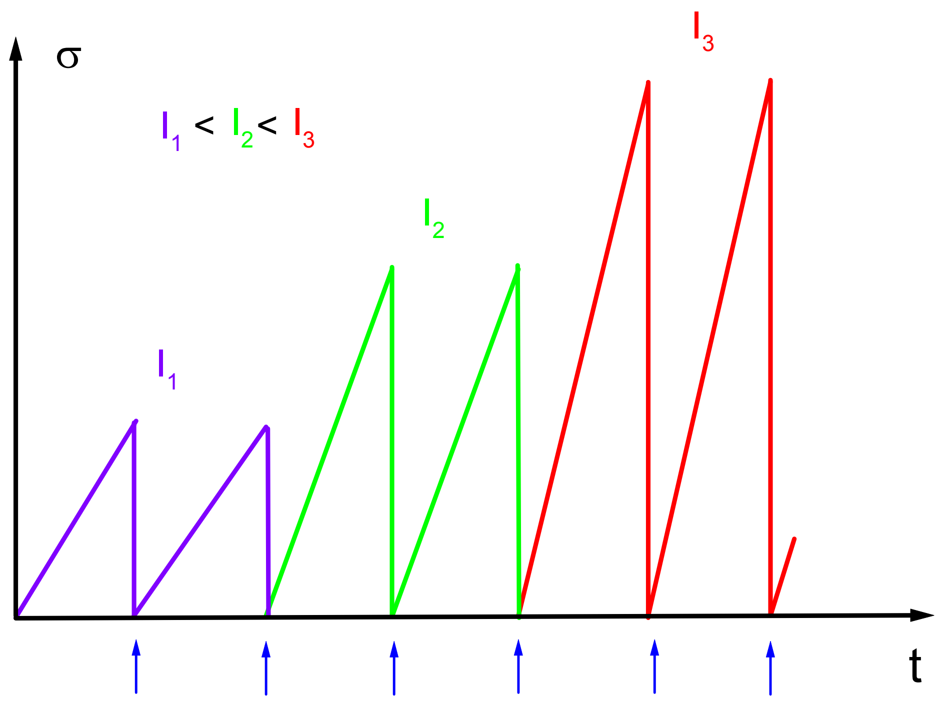
Long lifetime of the photoexcited electrons is due to a barrier between local and extended electron states – **DX-like impurity centers.**

Applied consequence: possibility of **internal integration** of the incident radiation flux.

Quenching of the persistent photoconductivity.

1. **Thermal quenching:** heating to 25 K and cooling down: too slow process.

2. **Microwave quenching:** application of microwave pulses to the samples



$f = 250$ MHz, $P = 0.9$ W, $\Delta t = 10$ μs

Quantum efficiency of the photodetector may be **increased up to ~ 10^2** in some special regime of the microwave quenching.

$Pb_{1-x}Sn_xTe(In)$-based infrared photodetectors

Radiometric parameters:

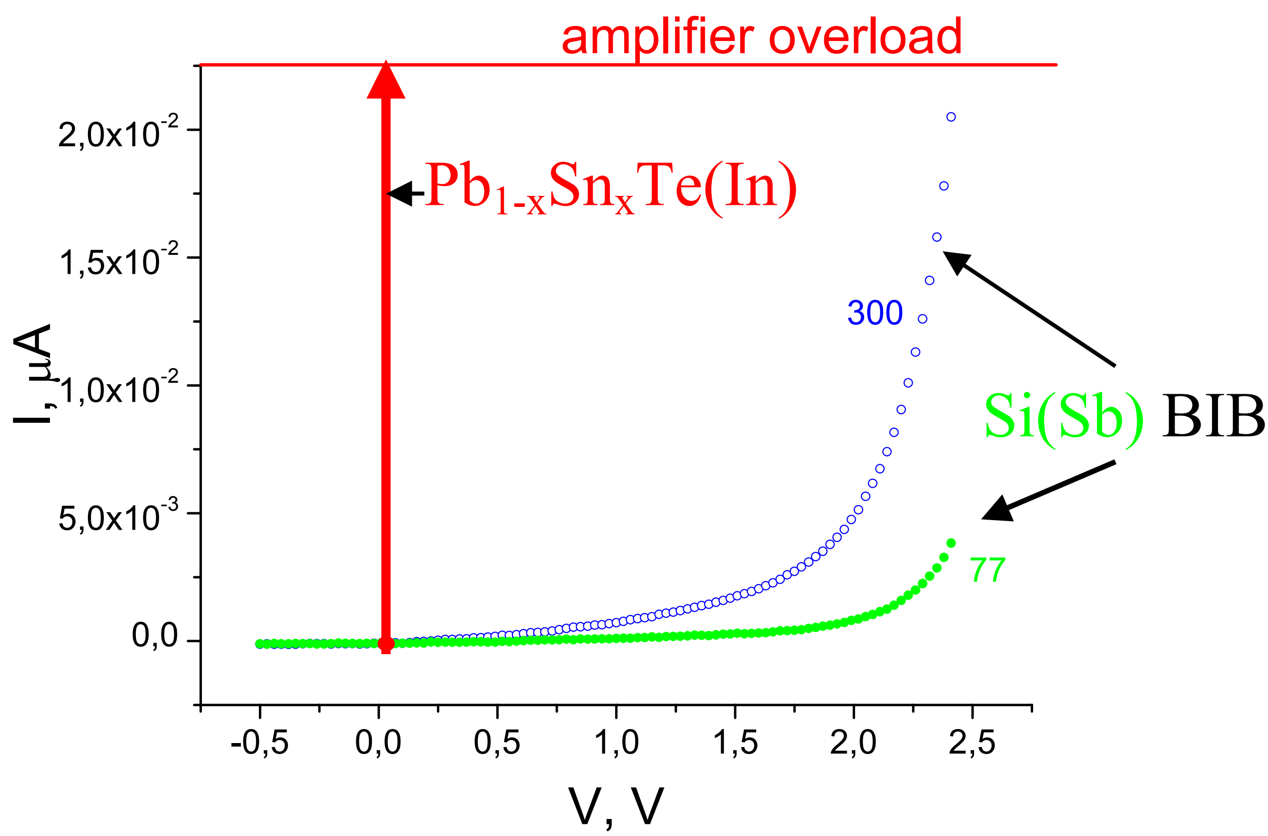
Single photodetector operating in the regime of the periodical accumulation and successive fast quenching of the photosignal, quantum efficiency stimulation regime.

- operating temperature 4.2 K;
- wavelenghth 18 μm (defined by the filter);
- operating rate 3 Hz;
- area 300*200 μm;
- current sensitivity > 10^7 A/W;
- minimal power detected < 10^{-16} W (sensitivity of the measuring electronics was only 10^{-7} A).

<u>Comparison with Si(Sb) and Ge(Ga).</u>

Direct comparison using the same cryogenic environment and measuring electronics.

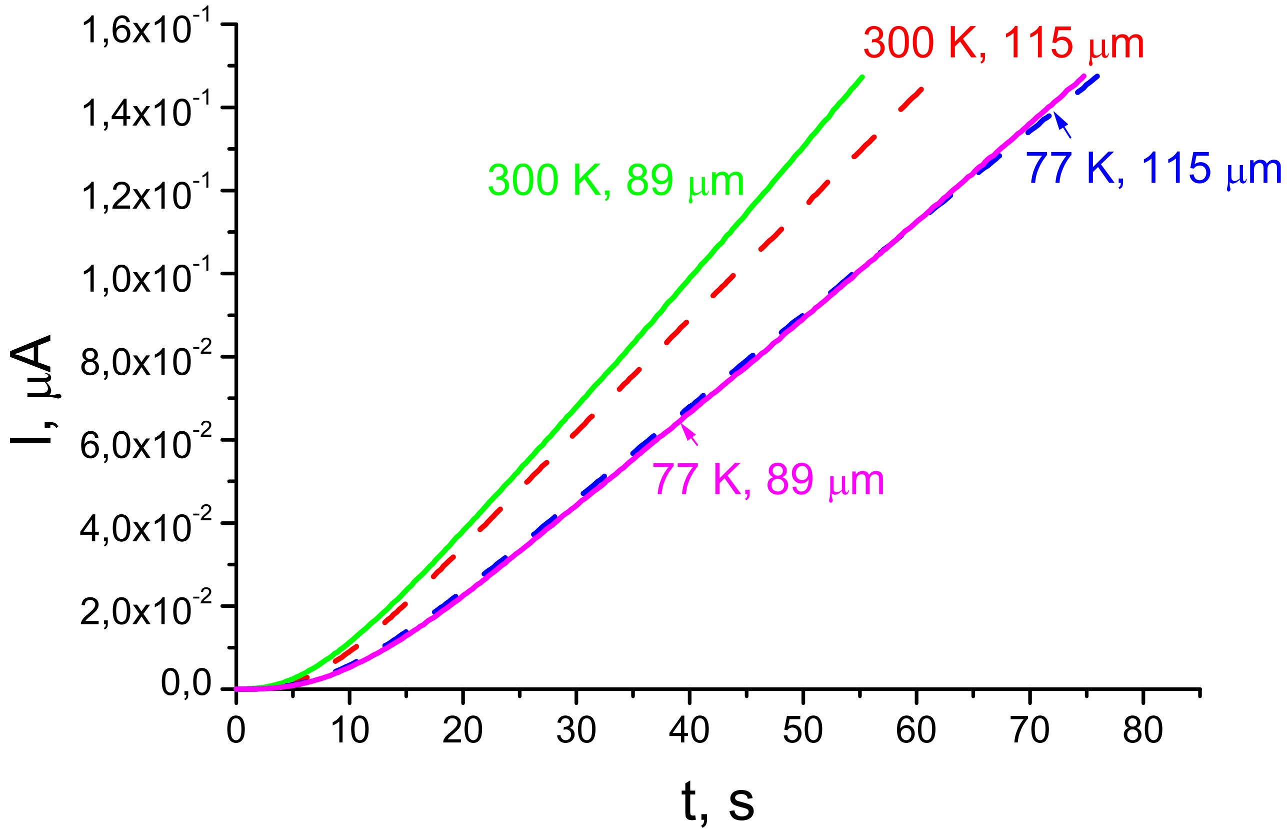
λ = 14 μm; state of the art Si(Sb) BIB



Figures near the curves – blackbody temperature.

$Pb_{1-x}Sn_xTe(In)$: **immediate** (< 1 s after the exposure start) amplifier overload at the minimal bias of 40 mV

λ = 90 μm and 116 μm, kinetics of response of the $Pb_{1-x}Sn_xTe(In)$ photodetector at 40 mV bias.

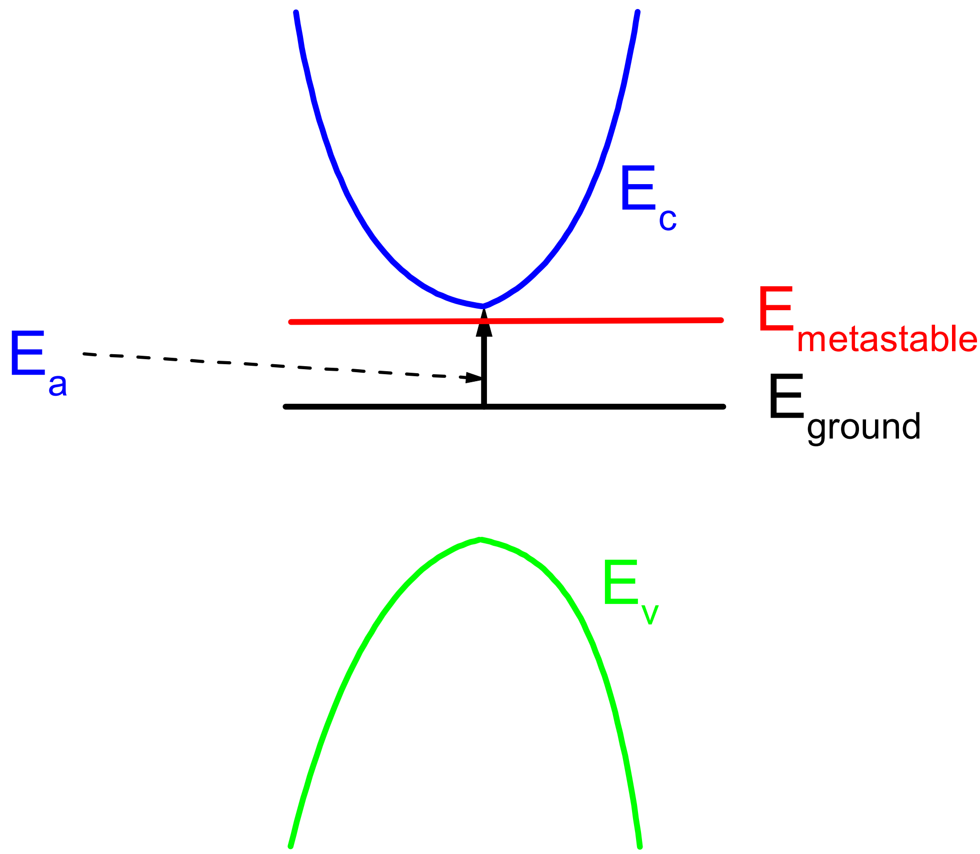


$Pb_{1-x}Sn_xTe(In)$: S_I~10^3A/W

State of the art Ge(Ga): S_I = (3.3-3.5) A/W

Extremely important:

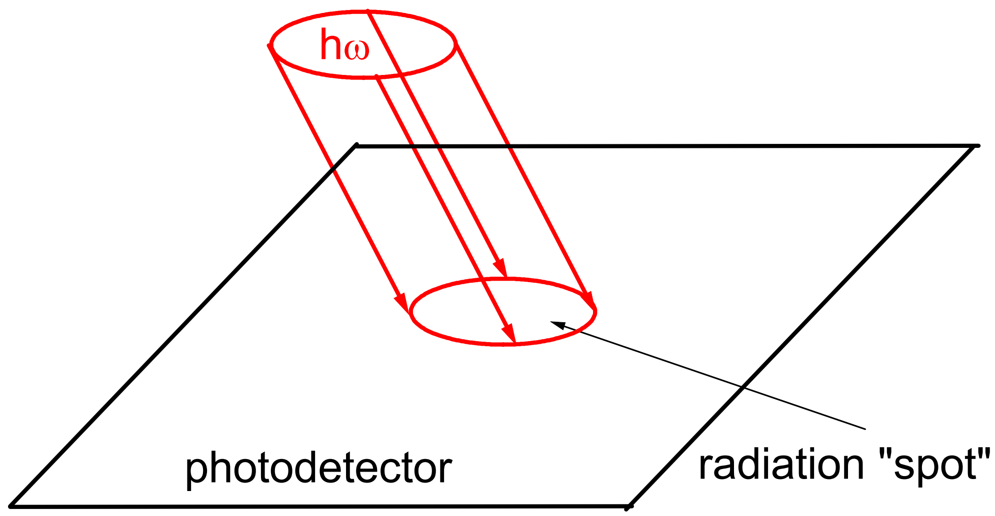
$E_{\lambda=(90,\ 116)\mu m} < E_a$



Photoresponse is due to excitation from **metastable excited local states**

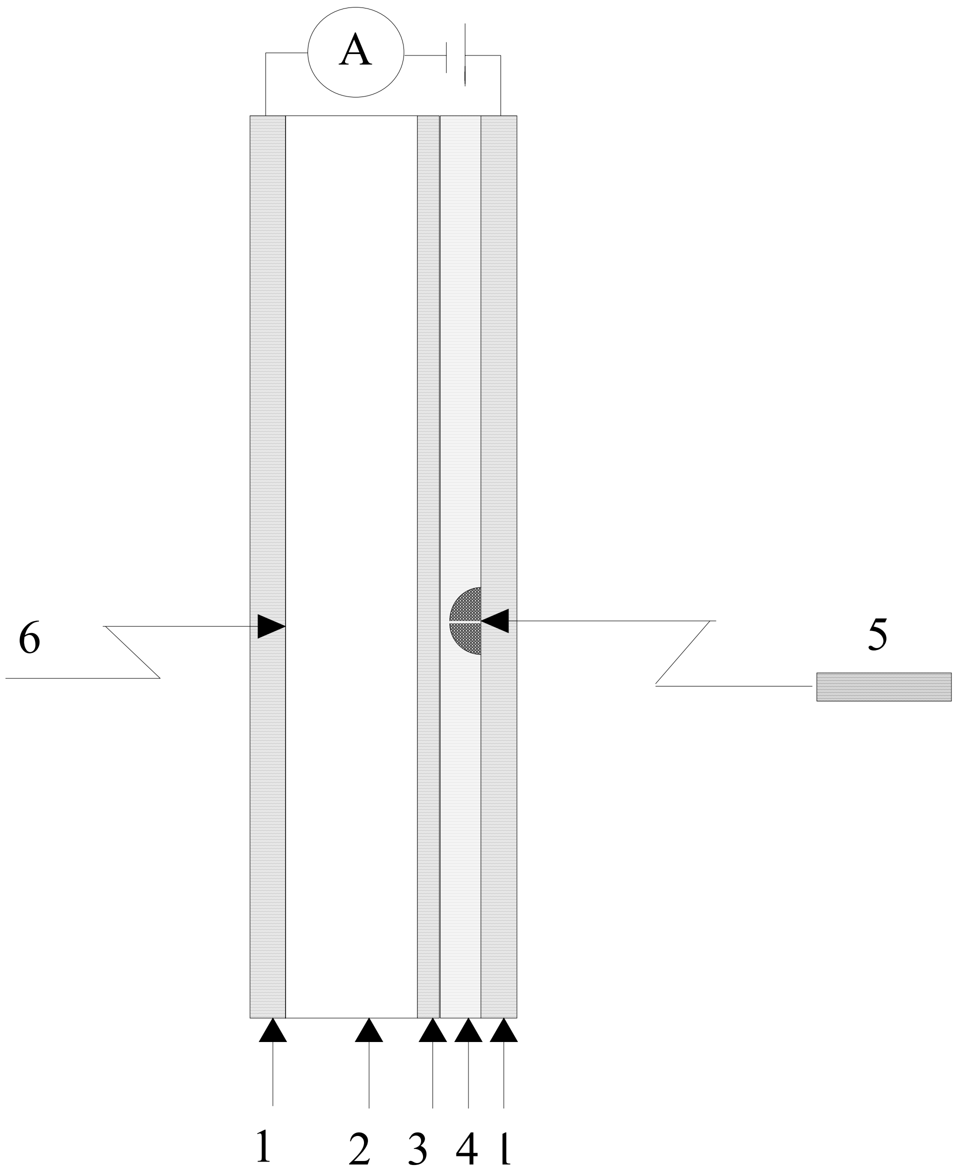
The cutoff wavelength $\underline{\lambda_{red}}$ may be **much higher than 220 μm**

Focal-plane “continuous” array.



Local infrared illumination leads **to local generation** of photoexcited free electrons, the photoexcitation does not propagate into the darkened regions. The spatial characteristic scale < 100 μm. **It is a focal plane "continuous" array, where the signal is internally integrated in every effective element.**

Idea of the readout technique



1 - semitransparent electrodes, 2 - active $Pb_{1-x}Sn_xTe(In)$ layer, 3 - fluoride buffer layer, 4 – wide-gap semiconductor layer, 5 - short-wavelength laser, 6 - incident infrared radiation flux.

SUMMARY

Application of the lead-tin tellurides doped with the group III impurities as base elements for the infrared photodetectors gives a promising possibility to produce universal and sensitive systems.

They have a number of advantageous features that allow them to compete successfully with the existing analogs:

1. **Internal accumulation of the incident radiation flux,**
2. **Possibility of effective fast quenching of an accumulated signal**
3. **Microwave stimulation of the quantum efficiency up to 10^2**
4. **Possibility of realization of a "continuous" focal-plane array**
5. **Possibility of application of a new readout technique**
6. **High radiation hardness**

These features make the $Pb_{1-x}Sn_xTe(In)$-based photodetectors ideal for the space-borne applications, for example, in the infrared astronomy.